# USE OF L- AND S-BAND TRANSMITTERS FOR OUTER SPACE APPLICATIONS

**PHILLIP A. UPDIKE**
**RF Engineering Department**
**Teledyne Telemetry Co.**

**Summary** This paper discusses six engineering problems associated with high reliability L- and S-band transmitters for use in space programs. The problems are:

1. Stable power in thermal vacuum
2. Low intermodulation products
3. Frequency stability
4. Isolation of power and modulation inputs
5. Efficiency
6. Size and weight

It is concluded that further improvements of primary transmitter characteristics, such as size, weight, frequency stability and efficiency will be determined by the rate of progress achieved by the electronic component manufacturers.

**Introduction** In 1966, Teledyne Telemetry Company developed a vented S-band transmitter for use on spacecraft. Variations of this design are now being used on several weather satellite programs, including TIROS, ESSA and Nimbus. This paper reviews some of the more challenging engineering problems that were encountered at Teledyne Telemetry Company in adapting this transmitter design to the weather satellite mission.

**Transmitter Performance Required by Typical Applications** The requirements placed on high-reliability L- and S-band Transmitters for space applications continue to become more stringent and demanding. The problems we found to be the most difficult to solve were the following:

1. Stable power in thermal vacuum environments.
2. Low intermodulation products when multiple closely spaced subcarriers are used to modulate the transmitters.
3. Frequency stability to .003% following shelf life of three to six years.
4. Electrical isolation of power input lines and modulation input lines from the transmitter case.

5. Increased DC to RF efficiency.
6. Decreased size and weight.

Stable power in itself is not a difficult parameter to obtain. The design that utilizes the vented technique, such that the transmitter sees the thermal vacuum environment and provides for internal isolation of circuitry from the transmitter case, creates a difficult design problem in the maintaining of stable power output.

The instabilities can be caused by differences in grounding, corona and/or multipacting. Power fluctuations caused by changes in ground return paths, as a result of temperature changes, have been observed and are known throughout the industry. The problems concerned with ground paths changing are, of course, more noticeable in S-band Transmitters than have been realized in VHF transmitters. In general, the S-band Transmitters require a cascading of more stages than are required in VHF transmitters and, therefore, the grounding problem is accentuated. Also, the ground return path inductances are more significant at the higher frequencies. When any metal-to-metal contact expands or contracts due to temperature changes, it naturally follows that the power changes are more noticeable. The incorporation of isolated circuitry in the design will tend to accentuate the possibility of varying inductance in the ground return path. The effect on output power, with changes in temperature, is to vary with the changes in ground return inductance.

The design employed in transmitters used on the TIROS, ESSA and Nimbus weather satellites, employs an isolated circuit design. These transmitters operate in the 1700 MHz region with nominal output powers of 6 watts. The power output of these units is highly stable. Units have been in orbit for over a year with no noticeable power output changes. The success of this isolated design can be attributed to a very careful layout of circuitry with ground techniques that employ careful mechanical attachments and tight tolerance controls. Metal chassis and mating assemblies are of the same material to utilize identical coefficients of expansions to minimize any changes in ground return paths. Isolation is accomplished by careful selection of the isolating material.

The effects of multipacting are still in the investigative stages. The phenomenon has only been discovered and studied within the last several years. Quantitative data is still extremely limited and in some cases contradictory. An extremely exhaustive study of this phenomenon was conducted by Hughes Aircraft for NASA which has shed some light on the problems involved with multipacting. This study points out that multipactor can occur when in low pressure, the mean free path for electrons becomes long compared with the containing vessel; also, the magnitude of the electric field and the phase of the electron motion with respect to the field must be in proper order to allow secondary emission of electrons by direct bombardment of the walls. The electric field must be at zero at the instant secondary emission occurs. If this reverses field polarity and accelerates the secondary electrons, the transit time, and therefore the distance across the gap is also a contributing factor for multipaction to occur. Because this type of breakdown is caused by secondary emission of electrons from the walls of the vessel, the breakdown field is shown to be independent of the type of gas and quite dependent on the nature of the walls of the containing vessel.

Multipactor discharge can be made to disappear by raising or lowering the applied voltage, such that resonance is no longer maintained within the vessel, by changing the frequency of operation or by increasing or decreasing the electrode separation. Multipactor discharge can be recognized by the pale blue glow that exists and by the deposited material on the electrodes. The deposits have a brown iridescent characteristic.

The cavity design used for the Nimbus/TIROS transmitters was tested for evidence of multipactor. Early designs exhibited multipacting. The design changes and process control implemented eliminated the problem.

Electrode spacing was changed by incorporating a different method of coupling. Tuning probes were separated from the tuning column by incorporating a different dielectric that will not outgas. The wall surface of the cavities was held to a very smooth finish and ultrasonic cleaning of all the cavities was employed. The multipactor discharge witnessed on these transmitters was random in nature, to the extent that it did not occur in the same place each time a test was performed. The chamber altitude was a contributing factor as to where the problem would occur.

Another interesting aspect of the phenomenon was that in no instance was the data being transmitted ever distorted, nor was the output power decreased to zero. The power variations were in the region of 2 to 4 db.

The Hughes report indicated that noise was present in the output spectrum as a result of multipactor occurring. There was no noise evidence during multipactor with the transmitters tested in our case.

The multipacting problem has not been witnessed in sealed transmitter designs but can be a serious problem if the seal is not 100% and has a slow leak rate such that the transmitter pressure reaches critical pressure for extended periods of time. The pressure level as described earlier can have an effect on the multipactor phenomenon.

The vented transmitter design has eliminated the concern of slow leak rates on seals. By careful selection of materials and component locations, this vented transmitter can be left on through critical pressure without any detrimental effects. Proper cleaning of all assemblies has an important role in the success of these units to perform without permanent degradation due to critical pressure. Ultrasonic cleaning is employed to remove any foreign material from the areas that could be subject to the multipacting phenomenon. It has been found that minute deposits of materials from fingerprints can contribute to the depositing of these materials during multipacting.

Low intermodulation products are a definite necessity with many systems presently being used. Multiple subcarriers spaced within 100 KC of one another are the common requirement in today's space hardware. The requirements for intermodulation products to be -45 db or less with subcarrier spacing of 100 KC creates a difficulty in the measurement of these parameters. Several methods of measurement have been evolved, but none of these methods has been as successful as first thought. The problem with measuring these products is to design a receiver that has a discriminator that is linear to enable measuring products -45 db or greater when the subcarriers are so closely spaced. The best results from these measurements have come from carefully planned test procedures and extensive care with the test equipment setup. The limitation of the receivers has a significant effect on the test results, and one must be completely familiar with the receiver being used and the technique for setting up the individual receiver for making these measurements.

The requirement for better frequency stability with increasing periods of shelf life have generated new problems in the L- and S-band Transmitter designs. Several design techniques are available for enhancing frequency stability. Closed-loop synthesis has provided the mechanism for tighter frequency control but has not solved the problem with component aging in its entirety. Close-loop synthesizers do not provide for DC response as is required in many cases and, therefore, may solve part of the problem of stability at the expense of other specification requirements. Study programs on the component aging problem are currently in progress to determine what can be done to designs and/or components to minimize frequency changes with aging of the components.

Several exciters have been used in one of the study programs. The aging rates varied from +45 Hz per day in the worst case to +8 Hz per day at the better end. The basic frequency used in these exciters is approximately 190 MHz. Additional compensation was employed to minimize the frequency change to less than 4.3 Hz per day at the exciter frequency.

This stability improvement will allow for an eventual realization of .003% after six years. Several other improvements have been made by pre-aging of components and design of circuits such that various parts of the circuitry tend to compensate in the aging process. Presently, suppliers of components, such as inductors, capacitors, and resistors seem to have differing opinions on the type of component or materials used in components that will provide the best aging characteristics. It appears that these studies will have to continue within the industry if reliable data is to be obtained at the component level.

The space applications for telemetry transmitters are continually calling for better efficiency, higher power, smaller size and weight. The increasing use of hybrid micro-electronic circuits and the higher frequency semiconductor devices will at least in the near future satisfy the desire for smaller size and weight. Improved DC to RF efficiencies at the higher power levels at S-band continue to be a problem in the industry. Specifications are currently calling for 10% minimum efficiency at 10 watts minimum output power over all combinations of environments. Some future requirements are now asking for 25% minimum efficiency at a power of 10 watts "S" Band. These requirements are placing a very challenging and difficult problem on the telemetry transmitter industry. Current state-of-the-art space transmitters can be supplied that provide a minimum output power of 10 watts with a minimum of 10% efficiency. However, the majority of the transmitters being supplied to the industry today are not the 10-watt minimum, but have minimum power of about 8 watts. Some new transmitter designs are now changing to direct power amplification at "S" Band which has improved the efficiency of S-band transmitters to 20% or 30%. The next milestone will be to provide power levels of 10 watts or more in the 2200-2300 MHz region.

The particular design used for long-term space satellites has been modular in nature so that adequate monitoring of transmitter performance could be accomplished. It is desirable to completely define performance of each section of the transmitter. In the event of performance degradation while in orbit, it is 4seful to isolate the problem area within the transmitter. To isolate problems in orbit so that studies can be made on other transmitters could prove somewhat troublesome. Parameters to monitor while in orbit would include output power, input current, ON/OFF telemetry, crystal current telemetry, and module input/out functions.

In conclusion, it is felt that the most difficult remaining hurdles in long life space transmitters will be:

1. Characterizing the component aging to predict long-term frequency stability, and
2. Being able to provide the user with a long-term guarantee on output power.

he size and weight of space transmitters will continue to decrease. The trend toward increased output power and efficiency for these smaller sizes will continue. Electronic component manufacturers will be the pacing factor in how rapidly the new smaller size transmitters will become available. Eliminating frequency multiplication, by operating power amplifiers at "S" Band, will be the most significant factor in reducing size and weight and increasing DC to RF efficiency.